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EXPERIMENTAL INVESTIGATION ON CORROSION BEHAVIOUR OF HOT UPSET P/M PLAIN CARBON STEEL

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ABSTRACT

The experimental work endeavors to examine the mechanism behind the corrosion phenomenon of sintered-hot upset plain carbon steel under induced corrosion acid pickling condition. The alloy powder mix of Fe-0.5%C was compacted into round specimens of size ϕ25x12mm utilizing 100T limit Universal Testing Machine (UTM) by applying necessary pressure to get 0.81 relative density Powder Metallurgy (P/M) plain carbon steel. The green compacts were sintered at a temperature of 1050±10ºC in a nitrogen purged muffle furnace for 30minutes. The sintered-hot forge upset alloy steel billets of 0.86, 0.90 and 0.98 relative densities were made to encounter aqueous corrosion attack by keeping the billets in a 250 ml pickling acid solution containing 18%HCL (Hydrochloric acid) for various time periods such as 25, 50 and 75hrs. It has been found that an increase in the density of specimens by hot upsetting results in a decrease in the number of pores present in the alloy steel. Though the plain carbon steel consists of soft ferritic-pearlitic microstructure, the densified specimens are found to be lower corrosive in action due to the formation of refined grain structure. Correlation for the corrosion rate relating density and testing time periods has been evolved and verified with experimental results are found to diminish straightly with lessening in porosity

KEYWORDS: Plain Carbon Steel, Sintering, Hot Upset, Microstructure, Corrosion Rate & SEM

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Original Article

INTRODUCTION

Today P/M ranks high among the major methods of manufacturing as it can produce near net shaped components with properties that are comparable with those of conventionally formed parts. Densification is one of the processes used for P/M components to improve mechanical as well as corrosion resistance properties. The corrosion research on P/M steels is of more importance in selecting the materials for various industrial applications such as structural, chemical, and marine industries. The conventional C45 steel has wide applications in various industrial sectors. The P/M alloy steel equivalent to the conventional C45 steel composition replaces the solid material almost in all the applications due to equivalent mechanical strength and better metallurgical characteristics. The corrosion studies on the P/M hot forged components are found less in the literature. Our experimental work takes the opportunity to fulfil the voids present in the research area. Kandavel, et al, (2012) have reported that the corrosion rate and iron loss are found to diminish in linear proportion with lessening in porosity for various chemical compositions of Fe-C-Cu-Mo-Ti sinter-forged low alloy steel under pickling acid medium. They have also found that the cold upset plain carbon steel is subjected to greater corrosion rate in comparison with plain carbon steel alloyed with Cu, Mo, and Ti, etc. Chandramouli, et al (2007) have reported lower levels of corrosion rate of Fe and Fe-1%C in HNO_3 aqueous agent with increment in the % theoretical density. They have reported

pore elimination and subsequent lower corrosion rates with increased density of cold or hot upset sintered alloys. Fachikov et al (2006) have reported that low-carbon steels (St.3 and KBC-290) alloyed with Cu, Ni, Cr, P, S, Si, & Mn elements exhibited greater corrosion resistance in aqueous solution corrosion medium of ammonium sulfate mineral fertilizer. Hong, et al, (2012) have reported decreased corrosion rate due to higher hydrogen formation and prohibition of the active dissolution in copper alloyed low alloy steels when exposed to sulphuric acid. Lopez, et al, (2003) have reported that the ferritic-pearlitic structure of carbon and low alloy steels and alloying with V, Ti, Mo, Ni, Si and Cu elements exhibited better resistance in CO_2 corrosion environment. Chandramouli, et al, (2010) have reported that the strength and microstructure of the P/M plain carbon steel are found to resemble like conventional C45 steel. Mehta, et al, (2010) have analyzed the effect of chromium on the corrosion behavior of Fe-0.45%P prepared by powder metallurgy by immersing in 0.25M H_2SO_4 and 3.5% NaCl solutions. They found that the addition of chromium increases the corrosion resistive property compared to Fe-0.45%P in the range of 0.6 to 6.8 pH. They have also concluded that the alloy made by powder metallurgy was poor in corrosion resistance due to the presence of pores. The corrosion rate of low carbon steel (SAE 1006) exposed for 21days in natural sea water was found four times lower than that of the steel exposed to synthetic sea water containing 3.5% NaCl solution due to the formation of oxy-hydroxides on the corroded surface as reported by Moller, H. et al (2006). Choi, et al,(2004) have analysed the effect of Cr, Cu and W added low carbon steel in synthetic potable water and found that the corrosion rate of steels containing alloying elements is heavily reduced. Uzhorh et al (2013) have conducted corrosion studies on two grades of plain carbon steel (DIN 35-2 and DIN 37-2) in three corrosive environments, namely salt solution (3% NaCl), tap water and moist soil. They have found that the corrosion rate of DIN 35-2 steel is higher than that of DIN 37-2 steel irrespective of the corrosive environments. The present investigation deals with corrosion studies on sintered hot upset Fe-0.5%C plain carbon steel under pickling acid medium at various time periods.

EXPERIMENTAL DETAILS

The powder mix of Fe-0.5%C was prepared by thoroughly weighing and mixing for 8 hrs in an in house fabricated pot mill. It was compacted into ɸ25x12 mm billets in a 100T capacity UTM by applying necessary pressure to get 0.81 relative densities performs of plain carbon steel. The green compacts were sintered at a temperature 1050±10ºC in a N_2 purged 3.5 kW capacity muffle furnacefor30min. The sintered specimens were once again reheated to a re-crystallization temperature (1000ºC) in an oil fired furnace and hot upset to attain various relative densities of 0.86, 0.90 and 0.98. The corrosion test specimens were prepared based on ASTM G31-2a standard. The Teflon tape covered specimen with 1cm^2 exposed areas was immersed in a 250ml pickling acid solution containing 18%HCl for different time periods such as 25, 50 and 75 hrs. After completion of the tests, the specimens were cleaned as per the standard procedure for further analysis. The mass loss due to the corrosion was found by weighing the specimen using SHIMADZU Digital Weighing Balance (Made in Japan) before and after the corrosion test. The microstructure and corrosion morphology of test specimens were examined in a KYOWA, ME-LUX2, CCD camera fitted with microscopehaving1000X magnification and interfaced with a computer and image analyzer. Micro hardness of the sinter-forged specimen was found using Shimadzu Micro Vickers hardness tester. The extent of corroded surfaces of the P/M alloy steel was recorded with TESCAN make SEM (VEGA3SB).

RESULTS AND DISCUSSIONS

A Corrosion Rate and Hardness of Hot Upset Plain Carbon Steel

From the test results of corrosion, tests on various relative densities of the P/M sinter-forged plain carbon steel, it is observed that the corrosion rate is decreasing with increase in relative density and time period for the test. Densification of P/M materials significantly improves mechanical, anti-corrosion and anti-wear properties. Hot upsetting is one of the densification process used for P/M components to get the desired density level. In the case of hot upsetting the grains are refined and elongated, which will add more strength to the materials apart from the coalescence of number of pores present in it. The densification of P/M alloy steel invariably increases the hardness of the material, which in turn enhances the mechanical strength and corrosion resistance property (Chandramouli, et al 2007).

Table 1: Experimental Test Plan and Results of Aqueous Immersion Corrosion Test Using RSM

No	Relative density	Time (hrs.)	Corrosion Rate(mmpy)
1	0.81	25.00	650.67
2		50.00	591.25
3		75.00	485.75
4	0.90	25.00	301.42
5		50.00	198.30
6		75.00	164.70
7	0.98	25.00	80.93
8		50.00	46.59
9		75.00	32.75

Figure. 1 shows the variation of micro hardness with corresponding relative densities of the P/M plain carbon steel due to the hot upset densification process. The hardness variation is almost linear with relative densities of the alloy steel. Maximum hardness value (200 HV) is achieved for the maximum relative density (0.98) and the least value is observed in the as sintered state (0.81 relative density) of the alloy steel.

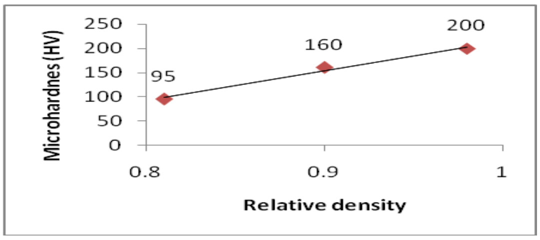


Figure 1: Variation of Micro hardness of the Hot Upset P/M Plain Carbon Steel With Respect to Various Relative Densities

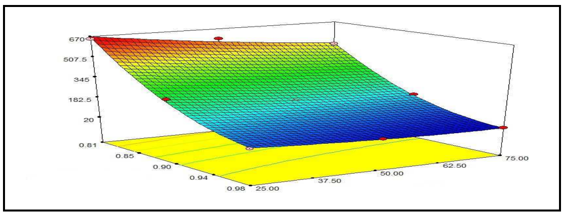


Figure 2: Corrosion Behaviour of the Hot Upset P/M Plain Carbon Steel

From Figure. 2 plots, it is known that the trend of variation of corrosion rate for any particular relative density of the alloy steel is not so steep with respect to time periods. On the other hand, the corrosion rate variation trend at any particular test time period is very steep with respect to relative densities of the alloy steel. It implies that the density of test specimen plays a vital role in corrosion behavior rather than the period at which the specimen is attacked with

corrosion medium. As sintered specimen is found to subject to higher corrosion loss in the acid medium compared to the densified specimens due to more number of large sized pores present in the material [2]. The initial corrosive action starts from the voids region and then propagates towards inward and other surface region. Moreover, the pore regions are the regions of higher surface energy level, which actively initiate the chemical reaction of material with the corrosion medium. That is why; the lower density P/M alloy steel is susceptible for greater corrosion attack than the well densified material. In the case of higher density P/M material, the pores are coalesced due to the densification process and the surface pore regions are eliminated to the maximum extent. The corrosion medium finds a rare place to initiate the corrosive action and thereby less corrosion attack on the higher density P/M plain carbon steel. The enhanced hardness of higher density alloy steel also found to improve the anti-corrosion property of material.

Correlations for the Corrosion Rate and Hardness of the Hot Upset P/M Plain Carbon Steel

We can calculate the corrosion rate at any relative density with respect to any test timing period by substituting the parameter values in the mathematical expression developed using DOE software as

$$CR = 14915.61857 - 28721.45146\ y - 17.0069\ z + 13.73412\ yz + 13944.92304\ y2 + 0.023827\ z2$$

Where, CR = corrosion rate (mmpy), y = relative density and z = time (hrs)

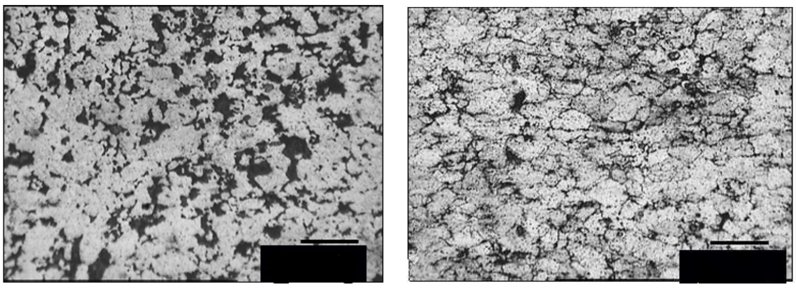
Also, the micro hardness of the sinter-forged material can be found for any relative density ranging from 0.81 to 0.98 of sinter-forged plain carbon steel using the generalized mathematical relation established using DOE software as follows:

$$H = -35518\ x3 + 95437\ x2 - 84605\ x + 24885$$

Where H = Vicker's microhardness and x = relative density

Microstructure of the Sinter-Forged Plain Carbon Steel

The common microstructure for as sintered and densified (0.98 relative density) P/M plain is observed as a ferritic-pearlitic as shown in Figure.3 (a) and (b). More number of open pores and larger size ferritic grains could be observed from the microstructure in the as sintered specimen (Figure. 3a).



(a) As sintered **(b) Densified**

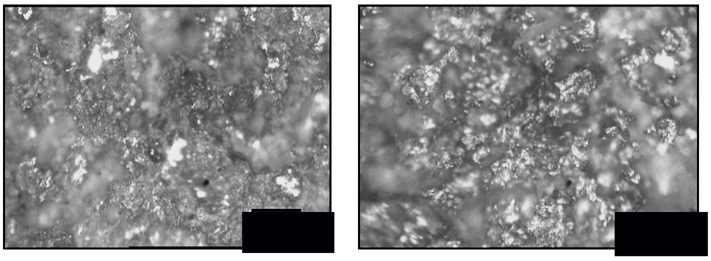
Figure3: Microstructures of the Sinter-Forged P/M Plain Carbon Steel

As sintered specimens experienced a higher corrosion, chemical attack due to the number of open pores and soft ferritic structure of the P/M plain carbon steel. The elongated, refined ferritic grains with lesser number of voids could be observed from the well densified P/M alloy steel. New crystals are found to be formed / refined and voids are coalesced during reheating and subsequent hot forging, which in turn strengthen the grain boundaries in the material. In

general, grain boundaries are the weakest regions to initiate the initial corrosive chemical action. In the case of well densified specimens, the higher binding energy between the refined grains adversely affects the chemical action of corrosion medium over the metal surface.

Optical and SEM Studies

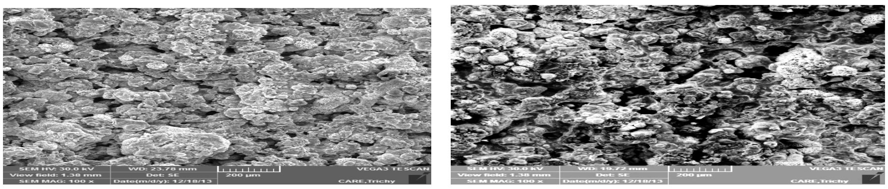
The optical and SEM morphologies of minimum and maximum corroded surfaces of P/M plain carbon steel are shown in Figures. 4 and 5. Figure. 4a illustrates the corroded surface image of the as sintered specimen. It is clearly evident from the figure that the uniform corrosion has taken place over the entire surface due to the soft ferritic microstructure. The oxide white patches could also be observed at some places. The corroded surface morphology of densified specimen of sinter-forged plain carbon steel is shown in Figure. 4b. The surface morphology indicates that the deeper corrosion has occurred at the grain boundaries as indicated at dark black region and the highest level of corrosion has occurred only in the ferritic region. It is understood from the image that the densified specimen has undergone non-uniform corrosion attack because of higher binding energy of refined grains. Moreover, the densified specimens are possessing higher strength and hardness, which makes the specimen less susceptible to the corrosive action in the acid medium.



(a). As sintered **(b) Densified**

Figure 4: Optical Images of the Maximum Corroded Surface of the Sinter-Forged plain Carbon Steel

Figure. 5a and 5b show the SEM images of sintered and densified plain carbon steel specimens after corrosion test duration. It is observed from the image (Figure.5a) that the uniform corrosion action has taken place over the as sintered specimen and the acid medium has gone to deeper level at the pores region.



(a) As Sintered **(b). Densified**

Figure 5: SEM Images of the Maximum Corroded Surface of the Sinter-Forged Plain Carbon Steel

On the other hand, the densified specimen underwent non-uniform corrosive chemical reaction as observed from the image (Figure.5b). It is also observed from the image that the ferritic region is subjected to higher corrosion attack rather than the pearlitic region in the case of densified alloy steel. However, the densified samples of plain carbon steel have undergone lower corrosion rate compared to the as sintered samples.

CONCLUSIONS

Presence of porosity in P/M material determines its corrosion behavior, enhancing the density of specimen by hot upsetting improves anti-corrosion property due to the formation of refined grains in the microstructure. Numbers of pores diminished with increased density levels as illustrated in the microstructure of sinter-forged plain carbon steel. Corrosion rate reduced with an increase in immersion corrosion time period. The higher binding energy between refined grains of ferritic-pearlitic microstructure in the hot upset densified P/M plain carbon steel increases the corrosion resistance of the alloy steel to a greater extent. The corrosion rate of the P/M plain carbon steel, exposure time and density have been correlated and also verified.

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